Impact of Mountain Pine Beetle on Stand Dynamics in British Columbia

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Abstract

A three-year research project was established in 2001 to examine the impact of mountain pine beetle on stand dynamics in British Columbia and southern Alberta. The project had three components: assessments of the effects of mountain pine beetle on stand dynamics; projection of mountain pine beetle impacts on stand and fuel dynamics with Prognosis[82] and the Fire and Fuels Extension; and estimation of mountain pine beetle outbreak and fire return intervals.

Permanent sample plots were re-measured after 10-19 years since establishment in 31 mountain pine beetle-affected stands in the Chilcotin Plateau, Kamloops and Nelson Forest Regions, and Kootenay and Waterton Lake National Parks. New permanent plots were established in 15 currently affected stands in Manning Provincial Park and Entiako Protected Area.

In total, 1631 lodgepole pine and non-host tree species cores were used to determine growth-release periods. In total, 272 tree cross-sections were examined and cross-dated for mountain pine beetle scars with 127 identified. This paper provides a summary of the project results.

Introduction

Lodgepole pine (*Pinus contorta* var. *latifolia* Dougl.) dominated stands comprise some 14 million ha of forestland in British Columbia (BC), roughly 25% of the provincial timber supply (British Columbia Ministry of Forests 1995). Between 1959 and 2002 a cumulative area of approximately 4.7 million ha of pine-leading stands have been affected by mountain pine beetle (*Dendroctonus ponderosae* Hopk.) (Taylor and Carroll 2004). The current outbreak was estimated to cover 4.2 million ha in 2003 (Data 2004).

A variety of silvicultural tools and management strategies can be used to reduce the risk of timber losses to mountain pine beetle before and during an infestation. Following infestation, salvage logging

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has been the main practice to recover some residual value from affected stands. Prescribed burning has also been attempted on a limited scale to renew lodgepole pine stands in protected areas. Because the amount of timber killed in the present outbreak is beyond the industrial capacity to extract and process, and because a large proportion of affected stands occur in protected areas such as Tweedsmuir Provincial Park, a significant proportion of affected stands will not be salvage logged in the short term.

An understanding of the impact of mountain pine beetle outbreaks on the growth and yield of surviving trees in residual stands, regeneration, woody debris dynamics and fire potential is needed for managers to make better decisions regarding management of residual mountain pine beetle affected stands.

Disturbance and Stand Structure

Lodgepole pine is a seral species in many ecosystems, but can be a self-perpetuating climax species where climate, disturbance, and edaphic factors limit the regeneration of other species (Agee 1993). Although lodgepole pine produces both serotinous and non-serotinous cones, permitting successful regeneration in either the presence or absence of fire, it is considered to be a fire dependent species (Lotan et al. 1985). The landscape level age-class structure of lodgepole pine can be described as a mosaic of even-aged and uneven-aged patches intermingling in space and time (Agee 1993). Whether a given patch or stand is even-aged or uneven-aged depends upon the disturbance history of the site; in the absence of fire, consecutive mountain pine beetle attacks in the stand contribute to the conversion of an even-aged stand to an uneven-aged stand (Roe and Amman 1970). Non-stand-replacement fires (i.e., surface fires) also lead to the creation of uneven-aged stands (Agee 1993), whereas high-intensity stand-replacement fires create even-aged stands. Lundquist and Negron (2000) developed a conceptual model of stand development in ponderosa pine that classified disturbance agents into two basic ecological functions. Firstly, new stands developed as a result of fire, wind, and epidemic populations of mountain pine beetle killing trees over large areas. Secondly, small-scale canopy gaps influenced stand development and structure due to a wide variety of factors killing small numbers of trees.

Impacts of Mountain Pine Beetle on Stand Dynamics

Forest stand dynamics are the processes of mortality, regeneration and growth. Heath and Alfaro (1990) examined a mixed Douglas-fir/lodgepole pine stand near Williams Lake, BC, where mountain pine beetle killed 76% of the pine in the early 1970s. In response to this natural thinning treatment (Peterman 1978), the radial growth rate of residual Douglas-fir was enhanced for 14 years after mountain pine beetle attack, suggesting the possibility that stand volume lost by the mortality in lodgepole pine might be compensated for by increased Douglas-fir growth by the time harvest rotation was reached. Release of remnant Douglas-fir and spruce post-epidemic was also observed in Wyoming and Idaho by Cole and Amman (1980). It is unknown whether there is release of surviving lodgepole pine in stands attacked by mountain pine beetle.

It is evident that the mortality imposed on lodgepole pine forest stands by mountain pine beetle attacks should influence fire behaviour: mountain pine beetle kills trees, changing both the quantity and spatial distribution of fuels in the forest. What is lacking is a link between the mortality rate of trees in lodgepole pine forests under attack by mountain pine beetle and the subsequent fuel loading of the stand over time. Mitchell and Preisler (1998) found that in unthinned lodgepole pine stands in southern Oregon, mountain pine beetle-killed trees began to fall to the forest floor after 5 years, with 50% of trees falling within 9 years, and 90% fallen by 14 years post-attack. Johnson and Greene (1991) found that it is possible to make reasonable post-fire disturbance estimates of tree-fall rates by examining trees already on the ground using equations of decomposition rates. Given the mass density of downed trees, rough estimates of the actual time of fall could be determined. They did not examine mortality due to mountain pine beetle attack. Using a retrospective approach, Turner et al. (1999) found that high severity mountain pine beetle attacks (>50% of trees killed) increased crown fire probability, but intermediate or light levels of

mountain pine beetle severity reduced crown fire probability during the wildfires of 1988 in Yellowstone National Park.

Stuart et al. (1989) and Mitchell and Preisler (1998) noted that the structure of lodgepole pine forests in central and southern Oregon were uneven-aged, with distinct episodic pulses of regeneration strongly correlated to mountain pine beetle outbreaks and fire. The magnitude of the regeneration pulse was a function of disturbance intensity. Delong and Kessler (2000) investigated the ecological characteristics of mature forest remnants left by wildfire in Sub-Boreal landscapes near Prince George, BC, and found some remnants had an uneven-aged, episodic pattern of lodgepole pine regeneration. Stuart et al. (1989) found that mountain pine beetle outbreaks were preceded by a decrease in the mean annual increment of the stand.

Projecting Mountain Pine Beetle Impacts on Stand Structure and Dynamics

Mountain pine beetle infestations result in variable mortality and create uneven-sized and mixed species stands across a broad ecological range in BC. Models are needed to project long-term impacts of mountain pine beetle on forest stand dynamics, fuels succession, and fire behavior potential. Models could help determine if release of other tree species maintained stand productivity through to scheduled harvest, the time course of fall down of mountain pine beetle-killed trees, and the structure and volume of the final harvest stand.

Taylor et al. (1998) used Prognosis[86] (Snowdon 1997) and the Fire and Fuels Extension (Beukema et al. 1997, 2000; Reinhardt and Crookston 2003) to project changes in fine and coarse woody fuels and potential fire behavior in relation to stand development for five locations in the dry forests of southern BC interior. Prognosis[86] (version 3.0) has been calibrated for much of southern BC interior (Zumrawi et al. 2002) and linked to the most recent version of the Fire and Fuels Extension may provide a useful framework for the modelling ecosystem development following mountain pine beetle attack.

In 2001, we began a project to determine the impact of mountain pine beetle on stand dynamics. This paper provides a summary of the project results.

Objectives

The mountain pine beetle stand dynamics project had three main objectives:

- Determine the effects of mountain pine beetle on stand dynamics (i.e., mortality, growth, structure, composition, regeneration, and fine and coarse woody debris accumulation rates) across a range of biogeoclimatic zones, stand conditions, fire regimes, mountain pine beetle outbreak frequency;
- Determine fire and mountain pine beetle outbreak recurrence; and
- Demonstrate/test the Prognosis[86] and Fire and Fuels Extension module to project stand dynamics (including fine and coarse woody debris), stand mountain pine beetle susceptibility, and potential fire behavior.

Methods

Impact of Mountain Pine Beetle on Stand Dynamics

Several researchers established plots to examine the initial impact of mountain pine beetle on stand structure during past outbreaks at a number of locations in BC and Alberta:

- Between 1933 and 1942, George Hopping (Vernon Entomology Laboratory) established 10 plots (seven 1 acre and three ¼ to 1 acre plots) in an infestation in Kootenay National Park. In 1993, Malcolm Shrimpton sampled four plots in the general area of some of the 1933 and 1942 plots.

- In 1980, Ben Moody (Canadian Forest Service, Northern Forestry Centre) established 25 plots in five stands in Waterton Lakes National Park.
- In 1987, Terry Shore (Canadian Forest Service), established 10 plots in each of 30 stands in the Chilcotin, five stands in the Kamloops Region and six stands in the Nelson Forest Region.
- In 1993, Terry Shore also established 10 plots in six stands in Kootenay National Park after an outbreak in the late 1980s and early 1990s.

In this component of the project we relocated, and if possible, re-measured these sample plots. In addition, we established new permanent sample plots in the current mountain pine beetle outbreak in order to extend the geographic and ecological range of the study (Fig. 1). The numbers of plots and characteristics are given in Table 1. We were able to relocate and re-measure all of the plots established by Moody and Shore in Waterton Lakes and Kootenay National Parks, respectively. We also relocated and re-measured 15 stands in the Chilcotin Plateau, four stands in the Kamloops Forest Region and one in the Nelson Forest Region; 21 of the original stands were heavily disturbed by logging or wildfire and could not be re-assessed. We did not re-measure the stands assessed by Hopping because they had been extensively disturbed and because we did not have the original field records. One stand in Kootenay National Park was not relocated.

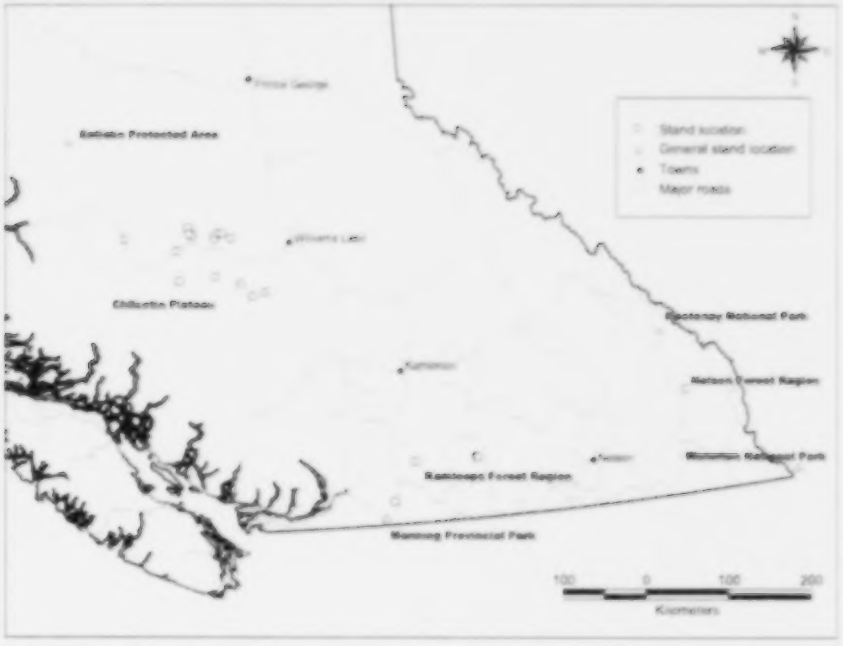

Figure 1 Location of mountain pine beetle stand dynamics project stands in BC sampled from 2001 to 2003.

In general, field data collection methods necessarily followed those used in the original studies. Prism plots were used to determine mountain pine beetle impacts on the dominant and co-dominant trees, while fixed area plots were used to sample pole-sized trees and regeneration.

Pre-outbreak standing live volume cannot be estimated simply by adding average standing dead volume in 1987, killed by mountain pine beetle, to the standing live volume. It is important to note that estimates of the impact of the beetle on stand density and volume in this study are snapshots in time.

We can state with accuracy what proportion of trees standing at the end of the outbreak were killed by mountain pine beetle, but this is a different estimate than if we want to relate mortality to initial stand conditions at the time the outbreak began. All stands were sampled using prism plots. Each tree represents a different sized plot, whose size is directly proportional to its diameter at breast height (DBH) included in the sample. A dendrochronological study will be providing data to determine the year each beetle-killed tree, sampled in 1987, died. This information will assist in knowing the time the epidemic began and the time period surviving trees grew before being sampled in 1987. For example, the potential error for pre-outbreak basal area could range from 10% to 21%, assuming most trees were killed in 1984 and over a 10 year period starting in 1977, respectively (Stockdale et al. 2004). In addition, if the surviving trees have grown prior to sampling in 1987, they would have occupied a smaller plot than they do today (Stockdale et al. 2004). A certain proportion of these trees, therefore, would have been too small to be included in a sample taken at the beginning of the outbreak. Without knowing the distance each tree is from the plot centre, we cannot determine precisely which of these trees in each sample should be removed from the sample pool. By not removing these trees from the sample pool, any estimates of pre-outbreak stand conditions would be overestimated in terms of density, basal area and volume, as we would be including too many trees in the analysis. Therefore, we will not provide estimates of pre-outbreak stand basal areas, volumes and densities in this paper.

In addition, coarse woody debris (>7 cm diameter) and fine fuels (≤7 cm diameter) were sampled along a 30 m randomly oriented transect in each plot. For coarse woody debris, the diameter and species of each piece, intersected by the transect tape, was recorded. Each piece was assigned to one of five classes of decomposition. Fine fuels were tallied along the first 2.5 m of the transect line using the method by Trowbridge et al. (1986).

In addition to the stand measurements, five pole-sized host and five non-host (if available) trees were cut at ground level in each of two DBH classes (0 - 3.9 cm and 3.9 - 7.5 cm). In the laboratory, 217 cross-sections (at ground level and 1.3 m - DBH) were sanded and examined for evidence of growth release. A release was defined as a period where tree rings showed an abrupt and sustained change in width, as judged by an experienced observer.

In 2002, ten study plots were established in each of five stands in Manning Provincial Park and eight study plots in each of ten stands in the Entiako Protected Area and Tweedsmuir Park. Protected areas were chosen so there would be a higher chance they could be re-measured in the future. Study stands were located in areas having recently experienced severe levels of mountain pine beetle activity.

Estimating Past Fire and Mountain Pine Beetle Outbreak Recurrence

The occurrence of past fire and mountain pine beetle outbreaks was inferred from release periods evident in tree ring cores and supplemented where possible with direct evidence from fire and mountain pine beetle scars in tree sections.

Increment cores were collected from lodgepole pine on all plots sampled, as well as from non-hosts (tree species not normally attacked by mountain pine beetle, if available). The cores (one per tree) were extracted at DBH with an increment borer parallel to the slope contour. The total number of cores collected in 68 stands was 1,337 lodgepole pine and 365 non-host tree species (Table 1).

Table 1 Number of mountain pine beetle stands established and re-measured and lodgepole pine and non-host species increment cores collected in BC and Alberta.

		Established		Re-measured		No. of cores	
Sample Location	Biogeoclimatic Sub-Zone	Year	No. of stands	Year	No. of stands	Lodgepole pine	Non-host species
Chilcotin Plateau	SBPSxc IDFdk4 MSxv	1987	30	2001	15	623 1987 230 2001	8 1987 30 2001
Kamloops and Nelson Forest Regions	MSdk IDFdk2 IDFdm1 MSdm1	1987	11	2001	3	88	19
Waterton Lakes National Park	Not available	1989-93	5	2002	5	46	17
Entiako Protected Area	SBSdk	2002	10			132	42
Manning Provincial Park	ESSFmw IDFdk2	2002	5			93	67
Kootenay National Park	Not available	1993	6	2003	5	94	94
Bull Mountain	IDFdk3	1975 1983	1	2002	1	93 2002	52 2002
Total			68		31	1537	863

Increment cores were collected in 2002 from lodgepole pine and Douglas-fir trees on Bull Mountain, near Williams Lake. The BC Ministry of Forests had surveyed this area in 1975 and 1983 to establish the amount and condition (alive or dead) of the overstory and understory. Cores were also collected from a nearby site that had not been affected by mountain pine beetle to confirm that any growth release detected was due to a thinning effect and not to a coincident period of abnormally favourable weather (Heath and Alfaro 1990).

Ring-width measurement was conducted using a Windendro© tree-ring measuring system and a Measu-Chron incremental measuring system. Chronologies were constructed using cross-dated ring-width series that were standardized using methods by Eisenhart and Veblen (2000). The standardized ring-width series were used to identify canopy disturbances (Veblen et al. 1991a). Each chronology was visually inspected for growth release that might indicate a mountain pine beetle outbreak. A growth release was called a mountain pine beetle release if it was abrupt and sustained over several years. The onset of a growth release was a year that exhibited a 50% increase with respect to the mean ring width of the previous five years. The end of a release was defined by the year when rings returned to pre-release levels. Thus, the start and end of the release was compared only with the tree-ring indices that directly preceded the release and not to the whole chronology. Releases that lasted less than 5 years were not used based on a similar method for detecting release in Engelmann spruce (*Picea engelmannii* Parry Engelm.) trees following spruce bark beetle outbreaks in Colorado (Veblen et al. 1991a, b).

Overall, but especially in the Chilcotin Plateau, it was difficult to find sufficient non-host trees to build reliable chronologies for species other than lodgepole pine. Four non-host chronologies were built for the Chilcotin Plateau and Kamloops and Nelson Forest Region samples. Non-host chronologies for other sampling locations are currently being completed. Non-host chronologies were examined to determine if periods of release in non-host species were synchronous with periods of release in lodgepole pine.

Recurrence of Mountain Pine Beetle and Fire Using Scar Dates

Both low intensity surface fire and mountain pine beetle strip attacks, which don't kill trees, leave scars which can be used to determine the year of disturbance. The characteristics we used to distinguish fire from mountain pine beetle scars are presented in Table 2. These were based on differences between fire and mountain pine beetle scars reported in Mitchell et al. 1983 and Stuart et al. 1983 supplemented with our own field experience.

A number of cross-sections were collected when the permanent sample plots were established in the Chilcotin. In addition, we examined a number of cross-sections that other researchers collected in the Chilcotin for evidence of mountain pine beetle attack (Fig. 2).

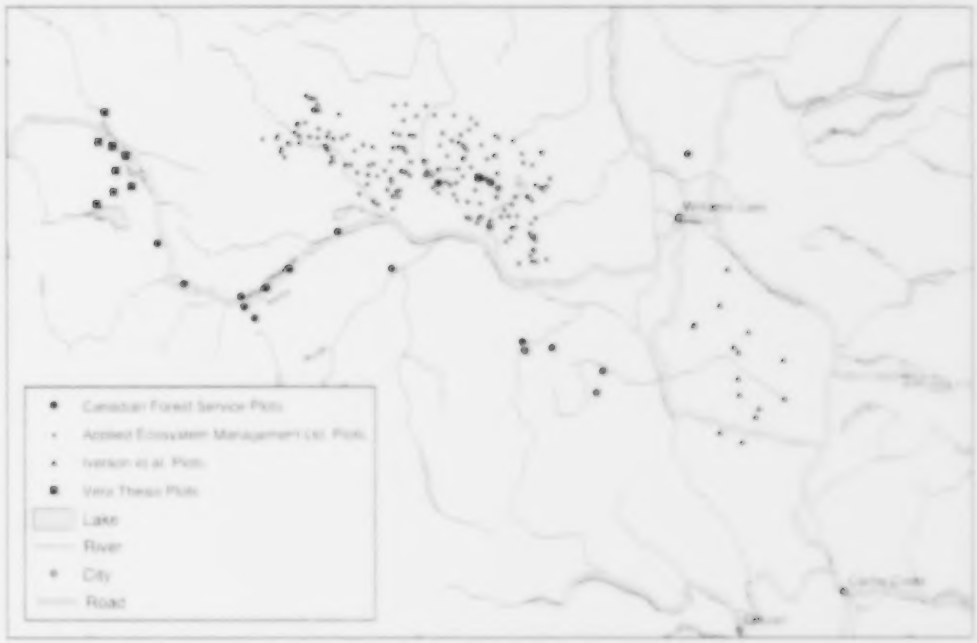

Figure 2 Sample location of fire and mountain pine beetle scarred discs and agency or individual that collected the samples.

The fire and mountain pine beetle disturbance dates determined from scarring allowed some limited analysis of the potential interactions of fire and mountain pine beetle in the Chilcotin Plateau. No cross-sections were available for the other sample areas. The number of scars and locations are given in Table 3. Canadian Forest Service cross-sections were cross-dated using the plot or plot closest to master chronologies completed in 2001 to 2002. Cross-sections from the Applied Ecosystem Management Ltd. project (2002) and Paula Vera's master's thesis (2001) were statistically cross-dated using a revised master chronology developed from the thesis. Marker years from these two projects were consistent with each other. Visibly narrow rings almost always present on each sample were dated at 1969, 1922, 1953 and 1951. Cross-sections from the Iverson et al. (2002) project were cross-dated using a master chronology already developed for that project.

In total, 272 cross-sections were examined and cross-dated for mountain pine beetle scars (Table 3). A total of 127 mountain pine beetle scars were identified from these cross-sections.

Table 2. Characteristics used to distinguish mountain pine beetle scars from fire scars.

Fire Scar	Mountain Pine Beetle Scar
Catface on bottom of tree without bark	Strip kill often has bark remaining on face
No blue stain fungus	Boring dust and vertical resin on scar face
Subsequent fires after the first one tend to be on the same side of the tree, even with different spread directions on flat ground	Mountain pine beetle galleries visible on dead section of tree
Usually no bark present on older scars, if present, lacking exit holes. Mitchell et al. 1983	Can be several scars around tree perimeter in same annual ring
Usually only one scar in the same annual ring	Visible entry points if bark still on, and blue stain fungus in dead cambium area
Generally scars do not occur in consecutive years	No charcoal on tree
	Can have scars in consecutive years

Table 3. Number of cross-sections examined.

Source	Biogeoclimatic Sub-Zone	Number of cross-section examined
Canadian Forest Service (this project)	SBPSxc IDFdk4 MSxv MSdk IDFdk2 IDFdm1 MSdm1	67
Applied Ecosystem Management Ltd. 2002	SBPSxc IDFdk4 SBPSdy SBPSmk	83
Iverson et al. 2002	IDFdk3	26
Vera 2001	SBPSxc	96
Total		**272**

Prognosis^{BC} and Fire Fuels Extension Module Projections

A total of 90 simulations using Prognosis^{BC} 3.0 and the Fire and Fuels Extension are being conducted to project the changes in stand structure, fuel loading and fire behavior for 15 stands in the Chilcotin Plateau, 10 in the Entiako Protected area, and 5 in Manning Provincial Park. As previously described, measurements for the Chilcotin Plateau stands were taken in both 1987 and 2001, resulting in two sets of stand data for this area. Each of the stands (including both data sets for the Chilcotin Plateau) is projected for two different scenarios: with mountain pine beetle mortality included and assuming no mountain pine beetle mortality. Simulations are done using 5-year time steps for 30-year projections.

The stand visualization system (McGaughey 1997) was also used to generate graphic images of each stand to depict stand conditions which is represented by a list of individual stand components, e.g., trees, shrubs, and down material. In addition, the mountain pine beetle susceptibility rating developed by Shore and Safranyik (1992) is being calculated for the sample stands, prior and post mountain pine beetle attack, to determine how stand susceptibility to mountain pine beetle attack changes with stand succession.

Results

Impact of Mountain Pine Beetle on Stand Dynamics

Stand dynamics results available to date are summarized in Table 4a, 4b, and 4c.

Table 4a. Post-outbreak and re-measured live tree volume and density by study area.

	Live tree volume m³/ha >7 cm DBH				Live tree density stems/ha >7 cm DBH			
Study area	Post Outbreak	n	Re-measured	n	Post Outbreak	n	Re-measured	n
Kamloops	193.1 21.2	5			535 28	5		
	218.2 29.9*	4	130.1 21.5	4	588 51*	4	377 84	4
Nelson	203.9 18.9	6			780 132	6		
	139.3 -*	1	163.9 -	1	441 -*	1	349 -	1
Chilcotin	88.7 8.5	30			756 52	30		
	87.2 11.3*	15	68.1 8.2	15	857 84*	15	546 52	15
Manning	193.3 34.0	5	-		616 69	5	-	
Entiako	63.2 11.0	10	-		643 123	10	-	

*1987 estimates for post-outbreak stands that were re-measured 2001.

Standard error of the estimate.

n Number of stands.

Table 4b. Post-outbreak and re-measured standing dead volume and density by study area.

	Standing dead volume m³/ha				Standing dead density stems/ha			
Study area	Post Outbreak	n	Re-measured	n	Post Outbreak	n	Re-measured	n
Kamloops	16.7 6.1 6.9	5			393 58	5		
	171.1 21.6*	4	96.7 25.1	4	776 66*	4	271 72	4
Nelson	91.8 16.6	6			336 83	6		
	64.4 -*	1	12.1 -	1	291 -*	1	120 -	1
Chilcotin	62.7 5.9	30			510 31	30		
	52.6 6.6*	15	17.4 3.4	15	289 34*	15	140 28	15
Manning	256.6 33.1	5	-		528 146	5	-	
Entiako	102.3 21.4	10	-		791 114	10	-	

Includes mountain pine beetle green attack at sampling time.

*1987 estimates for post-outbreak stands that were re-measured 2001.

Standard error of the estimate.

n Number of stands.

Table 4c. Post-outbreak and re-measured pole-sized tree and regeneration density by study area.

Study area	Live tree density: stems/ha <7 cm DBH >1.3 m height						Regeneration: stems/ha ≤ 1.3 m height					
	Post Outbreak		n	Re-measured		n	Post Outbreak		n	Re-measured		n
Kamloops	-			570	126	1	-			2111	709	1
Nelson	-			385	-	1	-			8344	-	1
Chilcotin	652	384	15	1422	292	15	4970 4687	540 857 *	30 13	4538	972	15
Manning	658	195	5	-			1364	274	5	-		
Entiako	944	390	10	-			727	204	10	-		

† 1987 estimate for pole-sized tree density based on 2001 sampled trees that were aged at DBH to determine if they met the criteria for pole-sized trees in 1987.

*1987 estimates for post-outbreak stands that were re-measured 2001.

Standard error of the estimate.

n Number of stands.

Chilcotin Plateau

Lodgepole pine is the most common tree species. A unique multi-age and size stand structure exists as a result of lodgepole pine being able to regenerate under its own canopy, and past multiple mountain pine beetle outbreaks and surface fires (Fig. 3).

Figure 3 Photograph of Stand 125, plot 2 in the Chilcotin Plateau illustrating the multi-sized lodgepole pine stand structure. A time period of 16 years has elapsed since the 1970s/1980s mountain pine beetle outbreak collapsed in the winter of 1985.

From 1987 to 2001, post-outbreak standing live tree volume and density was reduced, for the 15 stands re-measured in 2001, by 22% and 36% respectively, although there was significant variation due to differences in stand structure (Table 4a). Despite an increase in growth rates in smaller diameter residual trees, there still was a reduction in standing live volume and tree density from 1987 to 2001. This reduction in standing live tree volume was mainly the result of additional mountain pine and *Ips* beetle mortality that occurred from 1987 to 2001. Standing dead tree volume (caused by mountain pine beetle and other causes) was reduced on average by 67% and tree density by 52% due to fall down (Table 4b). Mountain pine beetle-induced mortality occurred mainly in the larger diameter trees.

In 2001, pole-sized tree density was two times higher than in 1987, based on a 1987 tree density estimate using 2001 sampled trees that were aged at DBH to determine if they met the criteria for pole-sized trees in 1987 (Table 4c). Lodgepole pine and aspen were the most common pole-sized tree species. Pole-sized trees varied in their response to a reduction in canopy closure by DBH class, stand location, species, and time since the last mountain pine beetle outbreak. Data analysis has not been completed to determine if mountain pine beetle-induced mortality levels among stands is related to pole-sized tree release, as well as, the pole-sized tree age.

Pole-sized lodgepole pine averaged 48 years old, ranging from 13 to 162 years. The time to reach DBH averaged 30 years in the Chilcotin Plateau. In the 0 - 3.9 cm size class, 21.2% of discs show a response during the 1990s. The 3.9 – 7.5 cm size class showed a lower release rate of 9.2%. Between the late 1970s and 2001, 96.6% of the pole-sized trees had demonstrated a release in growth.

Three historical periods of response in the pole-sized trees sampled in the Chilcotin Plateau were identified. These responses were related to known mountain pine beetle outbreaks in the 1970s, 1980s and 1990s. The first commenced in the early 1970s, lasting long enough to see a response in the tree ring widths in the middle 1980s. A second mountain pine beetle outbreak in the early 1980s resulted in a response in the early 1990s. The most striking response to the outbreak was the release of previously suppressed individuals of all species.

Lodgepole pine seedling density was recorded at the second highest density of all study areas and had similar densities in 1987 and 2001 (Table 4c). There was a minor amount of Douglas-fir, spruce, and sub-alpine fir in 1987. In 2001, Douglas-fir and spruce seedlings were still present in small numbers, sub-alpine fir seedlings had disappeared, and two new species, trembling aspen and willow, had appeared. Of these two new species, trembling aspen was the most abundant.

Mountain pine beetle influence on forest stand dynamics is similar to that of defoliating insects, which are known to improve the growing environment of surviving trees following an epidemic attack (Manson and Addy 1975; Wickman 1978). In younger stands it is the veteran large-diameter trees that are targets for mountain pine beetle attack. When the older trees die, smaller, younger trees in the stand may respond to the increase in resources available for growth. The mortality of lodgepole pine after a mountain pine beetle outbreak permits the accelerated growth of small Douglas-fir and spruce pole-sized trees or seedlings. This results in a shift towards shade-tolerant species over a longer period of time than if these tree species were part of co-dominant or dominant tree layers. This pattern of disturbance-mediated acceleration of succession also occurs following windthrow of lodgepole pine-dominated stands (Fox 1983; Veblen et al. 1991b).

The importance of accelerated growth as opposed to new seedling establishment following a mountain pine beetle outbreak is a major contrast to what is usually observed following high intensity fires where few trees survive (Veblen 1986; Apier et al. 1988; Veblen et al. 1991a, b). Stand replacement fires favour regeneration of lodgepole pine and other shade-moderant species that regenerate quickly. However, ecosystem responses following a mountain pine beetle outbreak may be less rapid, because surviving trees may be old and unable to respond and because mountain pine beetle-killed trees do not immediately drop their foliage (Waring and Pitman 1985). This would partially explain the release of pole-sized trees in the Chilcotin Plateau stands occurring throughout the last thirty years.

Fine and coarse woody fuel volume and loading results are presented in Table 5.

Table 5. Fine and coarse woody fuel volume and loading by study area.

Study Area	No. of Stands	Fine Woody Fuel < 7 cm m³/ha	Coarse Woody Fuel > 7 cm m³/ha	Fine Woody Fuel < 7 cm t/ha	Coarse Woody Fuel > 7 cm t/ha
Kamloops	4	16.8 (4.5)	222 (71)	6.9 (1.8)	91 (29)
Nelson	1	16.4 (-)	70 (-)	6.7 (-)	31 (-)
Chilcotin	15	12.9 (1.3)	66.9 (7.7)	5.3 (0.5)	27.4 (3.2)
Manning	5	10.3 (3.0)	117 (24)	4.3 (1.2)	45 (8.7)
Entiako	10	13.2 (2.1)	37 (14.3)	5.6 (0.9)	23.4 (5.8)
Waterton	4	16.1 (2.0)	103 (37)	6.8 (0.8)	42 (15.0)

Standard error of the estimate.

In 2001, fine and coarse woody fuel loading in the Chilcotin Plateau was the second lowest found in all study areas because of relatively low stand volumes (prior to the 1970s/1980s mountain pine beetle outbreak), growth rates, and tree mortality levels (Table 5). Snag attrition between 1987 and 2001 (caused by mountain pine beetle and other causes) made up most of the coarse woody debris sampled in 2001. If coarse woody debris had been measured in 1987, it would have been much lower than in 2001 since the previous mountain pine beetle outbreak to 1987 was from the 1930s to 1940s. Very few of the fallen trees from the 1930s to 1940s outbreak would have contributed significantly to coarse woody debris in 1987, due to 40-50 years of decomposition time.

Southern British Columbia

Kamloops Forest Region had four out of the five original 1987 sampled stands available for re-measurement in 2001, while the Nelson Forest Region only had one out of the six original 1987 sampled stands. Stand dynamics results for Nelson region stands are therefore limited to one stand, and cannot be used to project results for other areas in the Nelson Forest Region. Mountain pine beetle control and salvage activities accounted for the loss of six stands for potential sampling in 2001.

Although lodgepole pine was still the most common tree species in the stands sampled in the Kamloops and Nelson Forest Regions, many other tree species were present. Douglas-fir and spruce were the most common non-host tree species, especially in the larger DBH size classes, in the Kamloops Forest Region stands. Douglas-fir and western larch were the most common non-host tree species, especially in the larger DBH size classes in the Nelson Forest Region one remaining stand. An occasional fire scar provided some evidence of surface fires in the sampled stands in both regions; stands seem to have most often originated from stand replacement fires (i.e., crown fires). More even-aged multi-species stand structure existed in these regions as compared to the unique multi-age and size stand structure dominated by lodgepole pine in the Chilcotin Plateau.

In the Kamloops Forest Region, standing live tree volume in 1987 was twice as much as in the Chilcotin due to higher site productivity and tree growth in the southern BC interior (Table 4a). Although growth occurred in non-host large diameter species like Douglas-fir and spruce from 1987 to 2001, live volume decreased on average by 31% and tree density by 36%. The reduction in live volume was due to additional mortality that occurred from 1987 to 2001, especially by mountain pine beetle and *Ips* beetles. Standing dead volume (mountain pine beetle) was reduced on average by 44% and tree density by 26% due to snag attrition (Table 4b). The volume and density results by DBH size class indicated that mountain pine beetle mortality occurred mainly in the larger diameter lodgepole pine.

In the Nelson Forest Region, lodgepole pine, by volume, did not dominate species composition as much as in the Kamloops Forest Region. Standing live volume, for the one re-measured stand, increased

slightly from 1987 to 2001. Standing dead volume (mountain pine beetle) and tree density was reduced on average by twice as much as in the Kamloops stands (Table 4b). This may indicate a higher fall down rate in the Nelson Forest Region stand than in the Kamloops Forest Region stands although only one stand was used in the Nelson Forest region for this comparison. Douglas-fir and western larch volume, in the 25-30 cm DBH class, was over twice that of lodgepole pine in the Nelson Forest Region stand. This seems to indicate that a shift in species composition away from lodgepole pine in the co-dominant and dominant tree layers has occurred from 1987 to 2001, although there is only one stand to show this shift in species composition.

In 2001, pole-sized tree density in the Kamloops and Nelson Forest Regions was two to three times lower than in the Chilcotin Plateau stands but similar to Manning Provincial Park and the 1987 estimate for the Chilcotin (Table 4c). This pole-sized tree density difference was in spite of a higher tree density (> 7 cm DBH) in the Chilcotin Plateau stands (Table 4a). The pole-sized tree density in Kamloops and Nelson Forest Regions was half that found in the Entiako Protected area (Table 4c), even though the southern interior stands have less crown closure due to mountain pine beetle-induced mortality.

Seedling density in the one Nelson Forest Region stand was the highest recorded for all study areas, 2 times the seedling density in the Chilcotin Plateau (Table 4c). Seedling density in the Kamloops Forest Region was less than half that in the Chilcotin Plateau stands, but was greater than any other study area except the Nelson Forest Region.

In 2001, for both Kamloops and Nelson Forest Region stands re-measured, fine woody fuel loading was similar. Coarse woody debris was three times as high in the Kamloops Forest Region stands than in the one re-measured Nelson Forest Region stand (Table 5). This was mainly because two of the four stands in the Kamloops Forest Region were located in riparian leave strips that were surrounded by recent harvest openings, creating ideal conditions for windthrow of living lodgepole pine and other associated species. The coarse woody fuel loading in the Kamloops Forest Region stands was three times as high as those were in the Chilcotin Plateau because of the larger average lodgepole pine DBH in the southern interior and the windthrow that had occurred in the riparian leave strips. If coarse woody fuel loading would have been measured in 1987 in the Kamloops Forest Region, it would have been lower than that estimated for 2001 since the previous mountain pine beetle outbreak to 1987 was from the 1930s to 1940s in the southern interior. Very few of the fallen dead trees from those decades would have remained on the forest floor surface due to 40-50 years of decomposition. As well, the decomposition would have been more rapid in the southern interior stands since they have a wetter and warmer climate compared to the Chilcotin Plateau.

Manning Provincial Park

Although lodgepole pine was still the most common tree species in the stands sampled in Manning Park, Douglas-fir, interior spruce, sub-alpine fir, and western hemlock were present. Douglas-fir and spruce were the most common non-host tree species in terms of volume, especially in the larger DBH size classes. An occasional fire scar provided some evidence of surface fires in some sampled stands; most stands originated from stand replacement fires (i.e., crown fires). More even-aged multi-species stand structure exists as compared to the unique multi-age and size stand structure dominated by lodgepole pine in the Chilcotin Plateau.

In 2002, the standing live volume in Manning Provincial Park was over twice that in the Chilcotin Plateau in 1987 and Entiako Protected Area in 2002, but similar to Kamloops and Nelson Forest Region stands in 1987 (Table 4a). The higher standing live volume in Manning Provincial Park compared to the Chilcotin Plateau was due to higher site productivity and growth rates in the southern BC interior. Higher volume was found in Manning Provincial Park stands even though there was less mountain pine beetle mortality in the Chilcotin Plateau stands. More potential volume loss exists for Manning Provincial Park stands; since mountain pine beetle had attacked 19% of remaining standing live lodgepole pine in 2002. At the time of sampling, these trees were still alive. In 2002, standing dead tree volume in Manning Park

was the highest of all the study areas, while dead tree density was the second highest (a third less than Entiako Protected Area) (Table 4b). The volume and density results by DBH size class indicated that mountain pine beetle mortality occurred mainly in the larger diameter lodgepole pine.

In 2002, pole-sized tree density was the second highest in all study areas, with only Chilcotin Plateau stands having a higher density in 2001 (Table 4c). Douglas-fir, spruce, lodgepole pine, sub-alpine fir, and *Salix* spp. were the most common tree species in descending order of density. In the 3.9-7.5 cm-size class, Douglas-fir and spruce were the most common pole size tree.

Seedling density was the second lowest with the lowest density in the Entiako Protected Area (Table 4c). Douglas-fir, spruce, sub-alpine fir and lodgepole pine were the most common tree seedling species in descending order of density.

Fine woody fuel loading was the lowest of all the study areas (Table 5). The coarse woody fuel loading was twice that measured in the Chilcotin Plateau and half that measured in Kamloops Forest Region. Manning Provincial Park has larger diameter lodgepole pine than in the Chilcotin Plateau and a limited number of dead trees that have fallen down, as compared to stands in the Kamloops and Nelson Forest Regions. This would indicate that the sampled stands in Manning Provincial Park had a lot of natural thinning, blowdown, and coarse woody debris remaining from the previous stand that was disturbed by fire and gave rise to the present stands.

Entiako Protected Area

Lodgepole pine was the most common tree species in the stands sampled in Entiako Protected Area. Spruce, aspen, and *Salix* spp. were also present. Spruce was the most common non-host tree species in terms of volume, especially in the larger DBH size classes. An occasional fire scar provided some evidence of surface fires in some sampled stands; most stands originated from stand replacement fires (i.e., crown fires). Even-aged and sized lodgepole pine (with a minor component of spruce) stand structure existed as compared to the unique multi-age and size stand structure dominated by lodgepole pine in the Chilcotin Plateau.

In 2002, the standing live volume in Entiako Protected Area was the lowest of all study areas (Table 4a). In 2002, standing live tree density was similar to Manning Provincial Park but higher than the re-measured stands in the Chilcotin Plateau and Kamloops Forest Region (Table 4a). The low standing live volume in the Entiako Protected Area was the result of high mortality levels from mountain pine beetle and lower site productivity compared to Manning Provincial Park and the Kamloops and Nelson Forest Regions. There is only a small potential future volume loss in Entiako Protected Area stands from mountain pine beetle attack in 2002 since only 4.3% of the remaining standing live lodgepole pine had current attack. In 2002, standing dead tree volume was the second highest of all the study areas, while dead tree density was the highest (Table 4b). The high standing dead volume and tree density was the result of lodgepole pine dominating species composition, high pre-outbreak tree density of susceptible pine, and smaller diameter pine being killed due to high mountain pine beetle populations. The volume and density results by DBH size class indicated that mountain pine beetle mortality occurred mainly in the larger diameter lodgepole pine.

In 2002, pole-sized tree density was the second highest of all study areas, second only to the Chilcotin Plateau (Table 4c). Spruce, lodgepole pine, and trembling aspen were the most common species in descending order of density. In both pole-sized size classes, spruce and lodgepole pine were most common tree species. In 2002, seedling density was the lowest of all the study areas (Table 4c). Lodgepole pine, spruce, trembling aspen, and *Salix* spp. were the most common tree seedling species in descending order of density. The lack of living lodgepole pine in the overstory and relatively low numbers of non-host species of pole-sized trees and regeneration in the understory will result in slower stand succession than in southern BC interior stands. This is because in southern BC interior sampled stands, non-host tree species are more common in the co-dominant and dominant canopy layers than in the Entiako Protected Area stands.

Fine woody fuel loading was the third lowest of all the study areas but similar to the Chilcotin Plateau stands (Table 5). The coarse woody fuel loading was the lowest of all the study areas. Entiako Protected

Area has larger diameter lodgepole pine than in the Chilcotin Plateau but a limited number of dead trees have fallen down. When the high stand dead tree volume falls down, then coarse woody fuel loading will increase dramatically in the Entiako Protected Area. One compensating factor in reducing coarse woody fuel loading over time is that decomposition will probably be higher in the Entiako than the Chilcotin Plateau due to higher annual rainfall and temperatures in the Entiako Protected Area.

Mountain Pine Beetle Outbreak Recurrence

For the Chilcotin Plateau, 240 lodgepole pine cores were successfully cross-dated and included in the tree-ring analysis. The oldest core dated to 1758, while most dated back to the late 1880s (Alfaro et al. 2004). In all sampled stands there seemed to be fairly synchronous release periods, indicating possible mountain pine beetle outbreaks in the 1890s/early 1900s, 1930s/40s, and 1970s/80s. The latter outbreaks are consistent with Forest Insect and Disease Survey reports and other historical records (Wood and Unger 1996).

The period in the 1890s also had low intensity surface fires as indicated by fire-scarred lodgepole pine found in the Chilcotin Plateau. These surface fires would also have caused some growth release in stands such that the 1890s to early 1900s period cannot be confirmed as the result of only a mountain pine beetle outbreak. The standardized ring-width chronologies for the Chilcotin Plateau indicated a preliminary estimate for the duration of tree-growth release of one to two decades, while the time period between tree releases was roughly 40 to 50 years. Non-host species responded to canopy disturbance approximately at the same time as lodgepole pine.

Because not all lodgepole pine is killed in an outbreak and residual pine trees have been found to exhibit growth release, these trees could eventually become of susceptible size for attack by mountain pine beetle. At least three mountain pine beetle outbreaks during the 1900s and the ability of lodgepole pine to regenerate under the forest canopy, has led to a multi-age and size stand structure. In 2003, mountain pine beetle Ministry of Forests surveys showed light-severity mortality occurring in the Chilcotin Plateau. The growth release of lodgepole pine that started in the late 1970s and has continued to at least 2001, when stands were re-measured, seems to have been enough to increase mountain pine beetle susceptibility to a point where the stands are currently supporting a light severity mountain pine beetle attack.

Standardized ring-width chronologies from Douglas-fir trees on the Bull Mountain site showed a period of release after the last beetle outbreak in the 1970s. Heath and Alfaro (1990) documented this 1970s growth release. The Douglas-fir chronologies showed periods of growth release after periods of suppression that were inferred to be outbreaks by mountain pine beetle. Periods of growth release occurred approximately in 1760s, 1780s, 1860s, 1900s and 1920s. Standardized ring-width chronologies from surviving lodgepole pine trees showed possible mountain pine beetle outbreaks in the 1860s and late 1930s. Douglas-fir displayed a mean radial growth increase of 68% (0.55 mm) after the outbreak of mountain pine beetle in the 1970s. Lodgepole pine trees showed an increase of 58% (0.51 mm) in mean radial growth from the same time period. Fifty-two percent of Douglas-fir trees show a growth response in the five years after the mountain pine beetle outbreak in the 1970s as compared to 70% of the remaining lodgepole pine.

The most striking response to the mountain pine beetle outbreaks was the release of previously suppressed Douglas-fir and surviving lodgepole pine. Following the 1970s outbreak, growth rates for both species remained high for more than 20 years. The results from Bull Mountain indicate that in mixed Douglas-fir and lodgepole pine stands, if there is a significant amount of Douglas-fir in the stand, volume losses from mountain pine beetle-induced mortality in lodgepole pine could partially be offset by the increased growth of the remaining Douglas-fir.

Mountain pine beetle scars can be used in the same manner as fire scars for determining disturbance history. Mountain pine beetle and fire scars can occur on the same cross-section (Fig. 4).

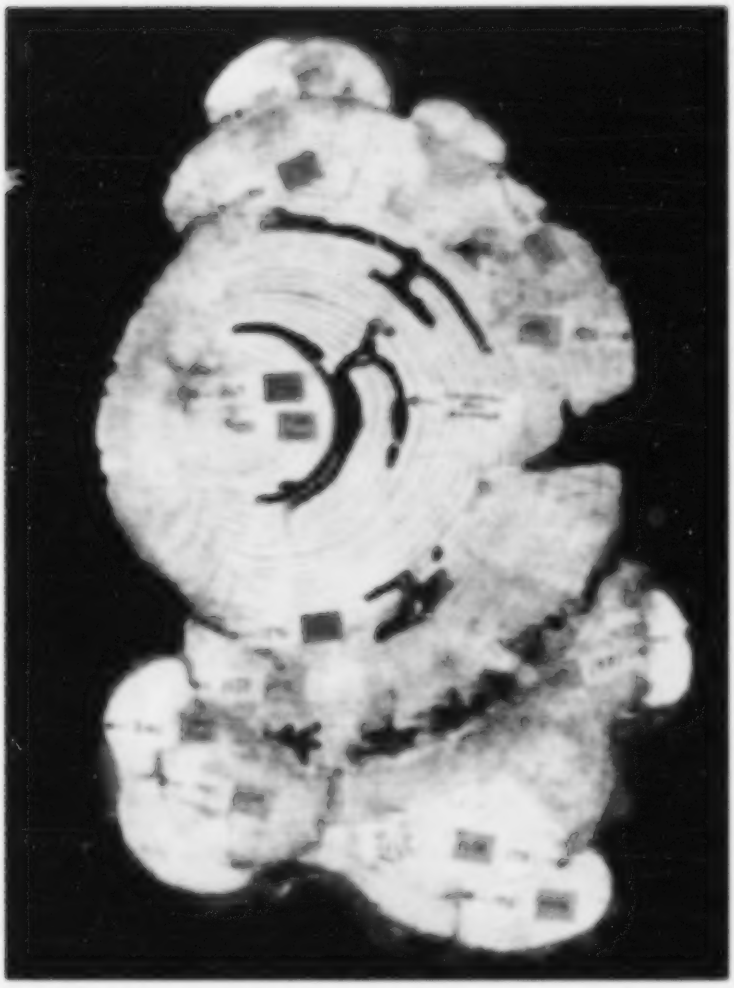

Figure 4 Mountain pine beetle blue- fire scars, and carpenter ant damage within a lodgepole pine tree disc from the Colorado Plateau (stand 12).

In examining 272 fire-scarred tree sections, 127 were found to have one or more mountain pine beetle scars (Table 3 and Fig. 3). The number of mountain pine beetle scars per tree ranged from 1 to 22 (1904). Fig. 3). On the trees (discs with) mountain pine beetle scars, a total of 81 fire years were identified (Fig. 3). The number of fire scars per tree ranged from 1 to 32 (1922. Fig. 3). Five years identified with 10 or more fire scars were in 1839, 1865, 1896, 1904, 1943, 1951, 1955, and 1956.

The number of mountain pine beetle and fire scars showed some interesting patterns over time (Fig. 3). Prior to 1903, only one mountain pine beetle scar was available to date a mountain pine beetle scar year and prior to 1839, less than 10 fire scars were found (Fig. 3). The reduction in the number of mountain pine beetle and fire scars over time was because very few lodgepole pines have been able to survive multiple fire and mountain pine beetle disturbances. The incidence of fire scarring appears to have declined since the early 1900s. Less than 10 fire scars were found after 1926 and no fire scars were found after 1962. This suggests that the incidences of surface fires has declined in these forests. The reasons for the lack of fire could include early efforts at fire prevention, introduction of fire control laws

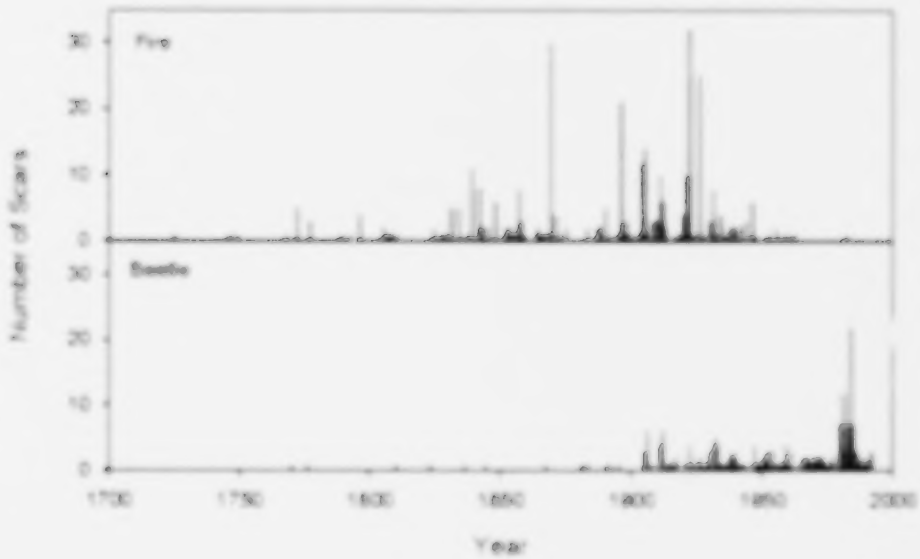

Figure 5 Number of mountain pine beetle and fire scars found on lodgepole pine trees close to, near to the Chilcotin Plateau.

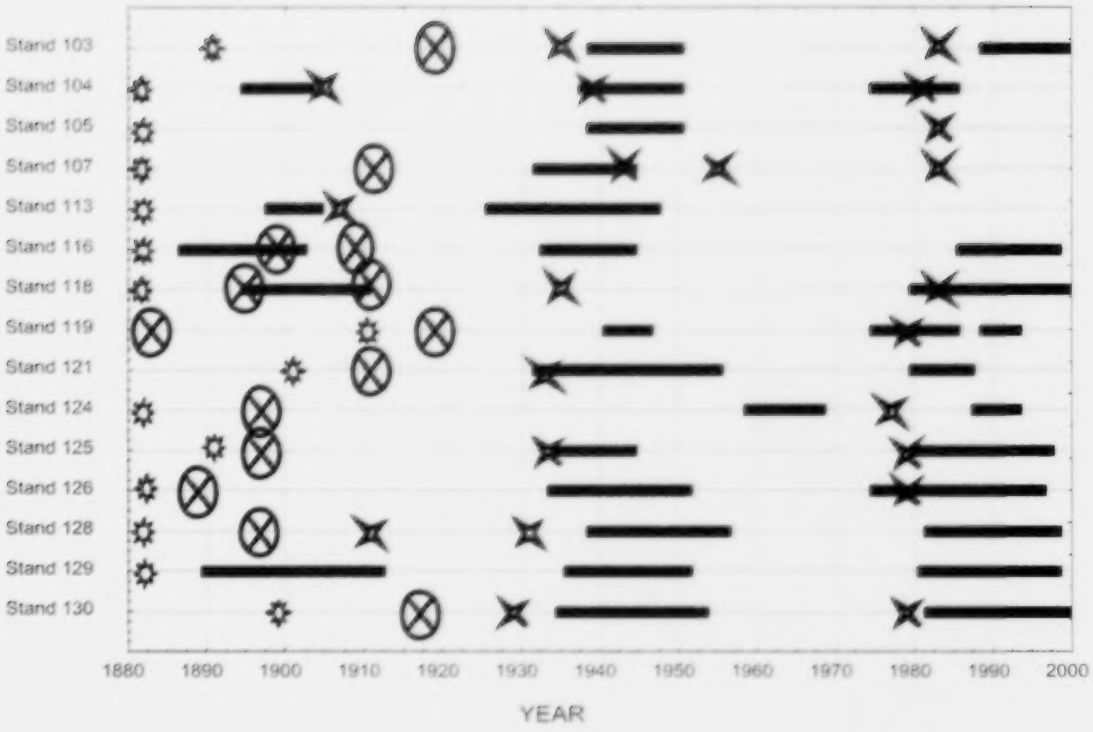

Figure 6. Release periods attributable to mountain pine beetle outbreaks in Chilcotin Plateau, BC, inferred from growth-release periods using tree-ring chronologies from Altaro et al. 2004). Fire circle with cross in middle and mountain pine beetle -star-shaped symbol- scar dates are given for each stand. Asterisk indicates start year for the tree-ring chronology.

One of the limitations of using these data from stands sampled in the Chilcotin Plateau after the 1970s to 1985 outbreak is that the results are mainly applicable to the SBPSxc and IDFdk4 biogeoclimatic subzones, in mixed-severity fire regimes, and in lodgepole stands with multi-age and size structure. The current mountain pine beetle outbreak in BC is occurring in more northern and wetter biogeoclimatic zones that experience crown fires at relatively long intervals and have more even-age and size stands. The plots established in the current outbreak area in Manning Provincial Park and Entiako Protected Area have expanded the project into other biogeoclimatic zones, but will not provide stand dynamics data for many years into the future. These plots have already provided mountain pine beetle impact information and are permanent plots that can be re-measured in future years.

Conclusions

The project results have made a significant contribution to our understanding of the impact of mountain pine beetle outbreaks on stand dynamics, re-occurrence rates for mountain pine beetle and fire, and woody debris dynamics. When modelling efforts are complete, there will be additional knowledge of woody fuel dynamics and fire behaviour potential. This type of information is needed for forest and fire managers to make better decisions regarding management of residual mountain pine beetle affected stands.

A number of conclusions can be made based on the stand dynamics results:

- The volume and density results by DBH size class for all study areas indicated that mountain pine beetle mortality occurred mainly in the larger diameter lodgepole pine.
- Lodgepole pine is the most common tree species in the Chilcotin Plateau study area. A unique multi-age and size stand structure exists as a result of lodgepole pine being able to regenerate under its own canopy, and past multiple mountain pine beetle outbreaks and surface fires.
- Despite an increase in growth rates in smaller diameter residual trees in the Chilcotin Plateau stands, there still was a reduction in standing live tree volume and density from 1987 to 2001 due to additional mountain pine and *Ips* beetle mortality that occurred from 1987 to 2001.
- In the Chilcotin Plateau stands, from the late 1970s to 2001, 96.6% of the pole-sized trees demonstrated a release in growth. Pole-sized lodgepole pine averaged 48 years old, ranging from 13 to 162 years with the time to reach DBH averaging 30 years.
- Seedling density in the Chilcotin Plateau stands had the second highest density of all study areas in 1987 and 2001. In 2001, lodgepole pine was the most common seedling, and two new tree species were recorded, trembling aspen and willow, of which trembling aspen was the most abundant.
- The importance of accelerated growth as opposed to new seedling establishment following a mountain pine beetle outbreak is a major contrast to what is usually observed following high intensity fires where few trees survive.
- Lodgepole pine was the most common tree species in the Kamloops and Nelson Forest Regions and Manning Provincial Park stands; although Douglas-fir, spruce, and western larch (Nelson) were present, especially in the larger DBH size classes. A more even-aged multi-species stand structure existed in these study areas due to stand replacement fires being more common than surface fires. Post outbreak standing live tree volume, in these southern BC interior stands, was twice as great as in the Chilcotin Plateau stands due to higher site productivity in the southern BC interior.
- Pole-sized tree density in the Kamloops and Nelson Forest Regions and Manning Provincial Park stands was two to three times lower than in the Chilcotin Plateau stands. The pole-sized tree density in Kamloops and Nelson Forest Regions was half that found in the Entiako Protected area, even though southern interior stands had less crown closure due to mountain pine beetle-induced mortality.
- Seedling density in the Kamloops Forest Region was less than half that in the Chilcotin Plateau stands, however it was greater than in any other study area except for the one stand re-measured in the Nelson Forest Region.
- There is still more potential volume loss in Manning Provincial Park stands since mountain pine beetle attacked 19% of the remaining standing live lodgepole pine in 2002. These trees were not dead at the time of sampling. In 2002, standing dead tree volume in Manning Park was the highest of all the study areas. When the standing dead trees fall over, coarse woody fuel loading will increase dramatically.

- Lodgepole pine was the most common tree species in the stands sampled in Entiako Protected Area, while spruce was the most common non-host tree species, especially in the larger DBH size classes. An even-aged and sized lodgepole pine stand structure exists due to stand replacement fires being more common than surface fires.
- In 2002, the standing live tree volume in Entiako Protected Area was the lowest of all study areas, due to high mountain pine beetle-induced mortality and lower site productivity compared to the southern BC interior stands. There is only a small potential future volume loss in Entiako Protected Area stands from mountain pine beetle attack since only 4.3% of the remaining standing live lodgepole pine had current attack in 2002. Standing dead tree volume was the second highest of all the study areas, while dead tree density was the highest. The high standing dead volume and tree density was the result of lodgepole pine dominating species composition, high pre-outbreak tree density of susceptible pine, and smaller diameter pine being killed due to high mountain pine beetle populations.
- The results from Bull Mountain indicate that in mixed Douglas-fir and lodgepole pine stands, if there is a significant amount of Douglas-fir in the stand, volume losses from mountain pine beetle-induced mortality in lodgepole pine could partially be offset by the increased growth of the remaining Douglas-fir.
- Fine woody fuel loading was similar in all study areas, while coarse woody fuel loading was the highest in the Kamloops Forest Region stands, due to two of the sampled stands being located in riparian strips that experienced significant blowdown of living large diameter trees of all species present. In 2001, coarse woody fuel loading in the Chilcotin Plateau stands was the second lowest found in all study areas because of the relatively low stand volumes, growth rates, and tree mortality levels.

A number of conclusions can be made based on the mountain pine beetle and fire re-occurrence and scar results:

- For the Chilcotin Plateau, all sampled stands seemed to have fairly synchronous release periods, indicating possible mountain pine beetle outbreaks in the 1890s/early 1900s, 1930s/40s, and 1970s/80s. The fire scar record indicated that the period in the 1890s had low intensity surface fires that might have also caused growth release in the larger diameter trees. The 1890s release period cannot therefore be confirmed as the result of only a mountain pine beetle outbreak.
- Mountain pine beetle scars can be used in the same manner as fire scars for determining disturbance history.
- On the tree discs with mountain pine beetle scars, a total of 83 fire years were identified. Fire years identified with 10 or more fire scars were in 1839, 1869, 1896, 1904, 1905, 1911, 1922, and 1926.
- The number of mountain pine beetle scars in any year ranged from 1 to 22 (1984).
- When mountain pine beetle scar dates were superimposed on the growth-release diagram, growth-release periods identified in each stand were found to be generally consistent with mountain pine beetle scar dates.
- The reduction in the number of mountain pine beetle and fire scars over time was because very few lodgepole pines have been able to survive multiple fire and mountain pine beetle disturbances.
- The incidence of fire scarring appears to have declined since the early 1900s suggesting that the incidence of surface fires has declined in these forests in the 20th century. The reasons for the lack of fire could include early efforts at fire prevention, introduction of fire control laws in the early 1900s, lack of aboriginal burning, fire suppression activities, and changing land use practices (e.g., grazing by large numbers of cattle and horses reducing grass fuels).

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